

747
7
710.13:3
U. S. DEPARTMENT OF AGRICULTURE
OFFICE OF EXPERIMENT STATIONS—FARMERS' INSTITUTE LECTURE NO. 3 (Rev.).
A. C. TRUE, Director.

SYLLABUS
OF
ILLUSTRATED LECTURE
ON
ACID SOILS.

BY
H. J. WHEELER, PH. D.,
Director, Agricultural Experiment Station, Kingston, R. I.



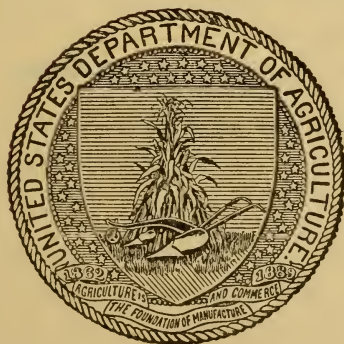
WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1907.



U. S. DEPARTMENT OF AGRICULTURE.
OFFICE OF EXPERIMENT STATIONS—FARMERS' INSTITUTE LECTURE NO. 3 (Rev.).
A. C. TRUE, Director.

SYLLABUS
OF
ILLUSTRATED LECTURE
ON
ACID SOILS.

BY
H. J. WHEELER, PH. D.,
Director, Agricultural Experiment Station, Kingston, R. I.



WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1907.

PREFATORY NOTE.

This syllabus of a lecture on Acid Soils, by H. J. Wheeler, Ph. D., Director of the Rhode Island Agricultural Experiment Station, Kingston, R. I., is accompanied by 53 lantern slides illustrating the topic. The syllabus and views have been prepared for the purpose of aiding farmers' institute lecturers in their presentation of this subject before institute audiences.

The numbers in the margins of the pages of the syllabus refer to similar numbers on the lantern slides and to their legends as given in the Appendix. Those in the body of the text refer to corresponding numbers in the list of authorities and references.

In order that those using the lecture may have opportunity to fully acquaint themselves with the subject, references to its recent literature are given in the Appendix.

JOHN HAMILTON,
Farmers' Institute Specialist.

Recommended for publication.

A. C. TRUE, *Director.*

Publication authorized.

JAMES WILSON, *Secretary of Agriculture.*

WASHINGTON, D. C., *November 1, 1904.*

ACID SOILS.

By H. J. WHEELER, Ph. D.

WIDE DISTRIBUTION OF ACID SOILS.

View.

The occurrence of acid soils in France, Germany, and other portions of Europe has long been recognized. It has also long been known that certain of the more important agricultural plants fail to grow satisfactorily, or die outright, in soils where a high degree of acidity prevails. Probably no more striking instance of injury to plants upon acid soils is on record in Europe than that in the department of Limousin, in France. There clover could not be grown, and the agriculture of the country was in a miserable condition for centuries until the construction of a railroad made it possible to introduce lime with which to overcome the sourness of the soil. After liming, clover succeeded, the cattle industry thrived, and an era of agricultural prosperity resulted. In parts of Massachusetts, New Hampshire, Rhode Island, Connecticut, New York, Illinois, Maryland, Virginia, Alabama, and other States acid soils exist, and hence the recognition of soil acidity is of great practical importance.

TESTS FOR ACID SOILS.

The most satisfactory way to have the soil tested is to send it to the local experiment station, where the chemists intrusted with such work are better able to judge from the tests how much lime to use than those who are making such tests for the first time or who have had but little experience. The best test for revealing the need of lime which is capable of being used by persons upon their own farms is that with blue litmus paper. Such paper can be bought of an apothecary at trifling cost. Strips half an inch wide and 2 inches long are convenient for making the tests. Care should be taken not to handle the end of the paper that is to be inserted in the soil, for if the fingers are moist they will redden the paper so that it will appear much as it does when reddened by acid soil. The soil to be tested

View.

should be moistened sufficiently with water to make a thick paste and should then be allowed to stand for half an hour or longer. It may then be parted by the use of a knife blade or other convenient instrument, and after introducing one end of the litmus paper the soil should be pressed against the sides of the paper. After from half an hour to an hour the paper may be removed from the soil, taking care not to tear it. After its removal the paper may be dipped repeatedly in water in order to wash off the adhering soil. If a distinct red color has entirely taken the place of the original blue color of the paper, it may be concluded that the soil probably needs liming.

In the case of very red soils it is often better to press the blue litmus paper against the soil than to have it surrounded by it. If in such cases the blue color of the paper disappears and gives place to a distinct red one, a need of lime is indicated. This blue litmus-paper test furnishes also a good means for testing for a lack of lime in subsoils, or soils very deficient in organic matter, where the acid substances may be largely of mineral origin. A good supplementary test, which is applicable only in soils containing considerable humus, is made by means of adding dilute ammonia water to soils. This can be bought of any apothecary at slight expense. In making this test take two glasses, place a level tablespoonful of soil in each, then add water until the glasses are about two-thirds full. Now add a tablespoonful of dilute ammonia water to one of the glasses. Stir each with a different spoon or knife. If, after standing some hours, the liquid in the one to which the ammonia water was added has become dark brown or black, it may be concluded that acid humus was probably present and hence that liming will prove helpful.

CORRECTIVES FOR ACIDITY.

In the case of soils which contain naturally enough lime in suitable form the humus does not get into the acid or sour state, but the acid substances which are formed during the decomposition of plants unite with the lime, forming what is known as "mild humus," and when such is the case ammonia water fails to give dark or black extracts, such as are obtained with soils containing "sour humus." If the soil is rich in lime, the inorganic compounds fail to become acid even in the subsoil or where little humus is present and the soil will not redden blue litmus paper.

Owing to the tendency of certain soils to acidity, it is important that there should be at least a small amount of lime (as

carbonate) present in the soil at all times, unless one desires to grow only such plants as thrive best under acid conditions. The chemical corrective of an acid is an alkali. Caustic or slaked lime is an alkaline substance, and its application is probably the cheapest, most effective, and most permanent means of correcting acidity in soils. When applied to the soil it changes under normal conditions largely to the carbonate of lime (the form in which it is found in limestone), and it is in this form that the larger part of the active lime of soils occurs. As pointed out later, however, other alkaline substances, such as wood ashes, carbonate of soda, etc., are effective means of correcting acidity.

Since the definite acidity or sourness of even upland, well-drained soils has been demonstrated, and simple tests for such soils have been pointed out, there is no reason why anybody should cultivate acid soils without being aware of it and without correcting the condition by liming, if desired. The tendency to acidity which exists in the case of all soils which lack carbonate of lime is much greater when certain artificial manures are used than where only stable manures are employed. Bone meal, tankage, and basic-slag meal gradually correct soil acidity, while the immediate effect of acid phosphate may be to make it more acid. Wood ashes correct acid soils quickly, furnishing potash to plants at the same time. The action of carbonate of potash is similar, though the quantity that would be used as a manure would not exert a very marked effect for the first two or three years. Kainit and muriate of potash are likely to increase the acidity of soils more rapidly than sulphate of potash. Blood, azotin,^a and certain other organic manures may promote acidity to some extent, but far less rapidly than sulphate of ammonia. Nitrate of potash is a safe source of both nitrogen and potash for acid soils, and nitrate of soda not only furnishes nitrogen but tends also to lessen their acidity.

With this brief review of a few of the more important facts relating to the acidity of upland soils, it may be of interest to follow some of the details of the investigations in this line which have been made at the Rhode Island Experiment Station.

POISONOUS EFFECTS OF SULPHATE OF AMMONIA ON ACID SOILS.

Attention was drawn to soil acidity at the Rhode Island Station in 1890 by the poisonous action of sulphate of ammonia, which materially reduced the yield of Indian corn, even when

^a Azotin is a nitrogenous fertilizer prepared from meat refuse.

View.

it was used in connection with potassic and phosphatic manures. The injurious action of sulphate of ammonia, when used together with muriate of potash, has been claimed by Brooks^{1 a} to be due to an interchange of bases and acids, by which ammonium chlorid (which he says is a plant poison) is formed, but it has been shown by Wheeler and Hartwell² that ammonium chlorid is itself a valuable manure if the soil is not acid; hence, if care is taken to correct undue soil acidity, there need be no fear of using sulphate of ammonia and muriate of potash in the same mixture; nor even of applying ammonium chlorid directly as a manure.

In the initial experiment³ at the Rhode Island Station sulphate of ammonia was used on unlimed soil at rates of 120, 240, and 360 pounds per acre, in addition to potassic and phosphatic manures. With each additional application of this substance the yield fell decidedly.

1 In the view now upon the screen, showing the crop of 1903, the three rows of Indian corn in the center were grown where but 240 pounds per acre of sulphate of ammonia were applied. Lime was applied to the soil at the farther end of the rows, where the Indian corn is seen to be taller.

2 A nearer view of the corn where the lime had been employed shows that the growth was excellent.

3 It will be observed that it was not, however, so good as upon the limed section, where 360 pounds of sulphate of ammonia had been employed. It was particularly striking that upon the unlimed soil each increase in the application of sulphate of ammonia reduced the yield, while where the lime was applied the yield rose decidedly with each application of the ammonium salt.

It was not alone at Kingston, R. I., that sulphate of ammonia acted injuriously, for similar results appeared the second and third years of its use at Hope Valley.⁴

4 The two lots of Indian corn at the left were grown at Hope Valley, R. I., by the aid of nitrate of soda, used as a supplement to potassic and phosphatic manures. The left-hand lot grew upon the limed area and the right-hand lot where lime was omitted. It will be seen that there was little difference in the results. This was due to the fact that nitrate of soda is a good and immediately efficient source of nitrogen for acid soils, and the soda present tends also to gradually lessen their acidity.

The two lots of corn at the right represent the yield produced where sulphate of ammonia was used under exactly the same condition as the nitrate of soda. It will be seen that the

^a Numbers refer to list of references on p. 28.

lot at the left, from the limed area, gives evidence of excellent growth. The poisonous effect of the sulphate of ammonia where lime was omitted is plainly shown by the corn at the right.

UNPRODUCTIVENESS DUE TO ACIDITY, NOT LACK OF LIME AS PLANT FOOD.

In order to determine whether acidity or a lack of lime as food was probably the fault of the Rhode Island soil, tests were made with Kingston soil upon four lots of lettuce,⁵ all of which were manured alike, with a mixture constituting a "complete" manure. Two lots of plants, represented in the view by stones, received no further treatment, and died while the plants were very small. The third lot from the right was grown where a one-half ration of sodium carbonate had been added to the soil, and the lot at the left where a full ration of sodium carbonate had been employed. Sodium carbonate is alkaline, and, like lime, is capable of reducing or overcoming soil acidity.

5

Trials of carbonate of lime and of sulphate of lime with beets⁶ showed the inferiority of the latter compound. This was to be expected if the fault of the soil was acidity, for the reason that in the sulphate of lime or land plaster the lime is combined already with a strong mineral acid (sulphuric acid), and can not, therefore, aid in overcoming the soil acidity until it has undergone a reduction and transformation into carbonate, a change which takes place but slowly in ordinary soils.

A further test was made with barley,⁷ the results of which will now be shown.

6

The two piles at the left represent the crop produced with phosphatic and potassic manures. In the case of the lot at the extreme left, however, 4 tons of air-slaked lime per acre had also been applied three years before, while for the second lot no lime had been used. The seven lots at the right all received potassic and phosphatic manures like the two at the left, and, in addition, nitrogen in sulphate of ammonia.

The poor result shown by the third lot from the left demonstrates the poisonous action of the sulphate of ammonia in acid soil. The fourth lot from the left differed from the third solely in the fact that 4 tons of lime per acre had been used three years before. In the case of the middle lot, the same amount of lime was used three years previously as in the good lot at its left, but the lime in this instance was combined

View.

with sulphuric acid (oil of vitriol) as sulphate of lime or land plaster, which was incapable of quickly correcting the soil acidity. To the fourth lot from the right caustic magnesia, which was capable of overcoming acidity, also corrected the condition. The third lot from the right received magnesia combined with sulphuric acid as sulphate of magnesia (Epsom salts), and hence it only corrected the condition slightly, if at all. It is possible that sulphate of lime or sulphate of magnesia may overcome the acidity of soils slightly and by degrees, particularly if they are moist and contain considerable organic matter, which two conditions are favorable to the partial elimination of the sulphur from the soil in a gaseous combination.

The two lots at the right had each received air-slaked lime three years before, at the rate of 1 ton per acre. The first two years the results were nearly or quite as good as where 4 tons of lime per acre were used, but it had now lost its efficiency. An addition of carbonate of soda, an alkaline substance, to the second lot from the right, though not made in sufficient quantity to equal the action of the large amounts of caustic magnesia or lime, nevertheless helped matters decidedly.

7 Other results with barley⁸ indicate that the soil under examination at the Rhode Island Station was helped by lime by virtue of its overcoming acidity. The nine lots of plants were manured alike with potassic and phosphatic manures, and nitrogen in sulphate of ammonia was used in like quantity in every instance.

Potassium was applied to the lot at the left, combined with chlorin as potassium chlorid, and hence it could not reduce the acidity of the soil. The second lot from the left received its potassium in potassium carbonate, an alkaline substance. The quantity used was small, but it nevertheless counteracted the acidity enough to show a distinct advantage over the lot at the extreme left. The third lot from the left received its potassium in wood ashes. The potassium in this case was probably wholly, or at least chiefly, present as carbonate of potash, and this alkaline substance was still further aided in overcoming the soil acidity by the large amount of carbonate of lime and the small quantity of carbonate of magnesia contained in the ashes.

The fourth, fifth, and sixth lots from the left received small, medium, and large applications, respectively, of sodium carbonate, an alkaline substance, which was beneficial, as will be seen, nearly in proportion to the quantity employed.

The three lots at the extreme right had received increasing amounts of magnesium carbonate in the same order. This sub-

stance also overcomes acidity, though in this instance the smallest amount was nearly sufficient for the purpose.

Still another experiment with barley⁹ verifies those already mentioned. The six lots of barley were manured alike with potassic and phosphatic manures and with nitrogen in sulphate of ammonia. To the lot at the left no further addition had been made. The plat represented by the second lot from the left had received one ton of air-slaked lime per acre several years before, but it had now lost the power, which it retained for the first few years, of correcting the acidity. The third lot had received several years previously four times as much air-slaked lime as the second lot. The fourth lot from the left had received caustic magnesia, which was highly effective in correcting the poor conditions. In the instance of the lot next to the right, where sulphate of magnesia had been employed, doubtless some of this substance had changed into carbonate of magnesia by reduction and elimination of sulphur in a gaseous combination; nevertheless, the result was poor as compared with that obtained with caustic magnesia, which latter compound was far better able to reduce the acidity of the soil.

The lot at the extreme right was grown under the same conditions as the second one from the left, with the exception that it had received a generous application of carbonate of soda.

It will have been observed throughout that marked and lasting improvement of the soil conditions resulted only in cases in which such materials as were capable of reducing or overcoming soil acidity were employed. While there can be no question but that these substances improved the physical properties of the soil in certain cases, and in some instances doubtless proved of some value as direct plant foods, the evidence that their beneficial action was chiefly by virtue of neutralizing acidity appears to be indisputable. It seems to be established by these experiments that certain upland and well-drained soils are sufficiently acid to seriously injure certain plants, and that the condition of the soil in this respect is capable of being greatly injured or being much benefited, dependent upon the manures employed.

AVAILABILITY OF NITROGEN AS AFFECTED BY ACIDITY.

The influence of soil acidity upon the assimilability of nitrogen,¹⁰ as determined at the Rhode Island Station, is exhibited by the two views which follow. In both instances nitrogen, when used, was applied at the same rate per acre. The lots of

View.

plants shown in both views had at their disposal like amounts of potassic and phosphatic manures in every case.

- 9 The view now upon the screen shows the relative efficiency of various nitrogenous manures upon acid unlimed soil.

The plants at the left illustrate the result without nitrogen. The second lot from the left shows that nitrogen in sulphate of ammonia proved positively poisonous, the result being poorer than that at the extreme left, where nitrogen was omitted. The third lot from the right received nitrogen in roasted and finely ground leather, the second lot from the right had nitrogen in dried blood, and the one at the extreme right was manured with nitrogen in nitrate of soda.

- 10 Upon the same soil the efficiency becomes vastly different after liming, when all of the manurial and other conditions are identical with those in the previous instance. All of these lots, excepting the one at the extreme left, were grown upon limed soil. Hence a comparison of the lot upon the extreme left with that at its immediate right shows the direct benefit to the barley due to overcoming or reducing the soil acidity, and the benefit produced by increasing the assimilability of the soil nitrogen. The lime doubtless also helped to some extent to improve the physical condition of the soil.

The four remaining lots show the results with nitrogen in nitrate of soda, dried blood, leather, and sulphate of ammonia, in regular order from right to left. Upon the limed soil the efficiency of the nitrogen of sulphate of ammonia rose to 92.2, as compared with nitrogen in nitrate of soda at 100. Thus it became a valuable food instead of continuing to be a poison. The efficiency of the nitrogen of dried blood rose upon the same basis, as a result of liming, from 45.5 to 90.3, and of leather from 0.9 to 13.8.

RELATION OF ACIDITY TO POTATO SCAB AND OTHER DISEASES

At the Rhode Island Station it appears to have been demonstrated positively, for the first time, that soil acidity is antagonistic to the disease known as potato scab, and that the reason why wood ashes, lime, stable manure, and other alkaline substances promote the disease is that they tend to overcome or lessen the soil acidity.¹¹ Where all the potatoes in a given experiment were manured in an identical manner with commercial manures, sulphate of lime (ordinarily known as land

plaster), and calcium chlorid, which were incapable of overcoming the acidity, did not tend to promote scab, though the reverse was strikingly true of air-slaked lime, carbonate of lime, and wood ashes. A like result was also obtained with calcium oxalate and calcium acetate, two substances which change readily in the soil into carbonate of lime.

In the first view of the potatoes grown under the conditions just mentioned the scabbed product resulting from the employment of air-slaked lime is seen at the left. The lot at the right grown with the regular manure was absolutely free from scab. 11

The lot at the left in this view received lime which was already combined with sulphuric acid and which was not likely to noticeably lessen the soil acidity. The lot at the right received calcium chlorid, which would be even less likely than the sulphate of lime to reduce acidity. In the former case only 4.3 per cent of the tubers had any scab spots (none being badly scabbed) and in the latter case no scab resulted. 12

This view presents on the left the result with carbonate of lime and on the right with oxalate of lime (calcium oxalate). In the former case 97.5 of the tubers were badly scabbed and in the latter all were badly scabbed. 13

The last view in this connection shows upon the left the result with acetate of lime (calcium acetate) and on the right with unleached wood ashes. Where the acetate of lime was used every tuber was scabbed so as to be unfit for market, and where the ashes were used all were scabbed and 93.3 per cent of them were rendered thereby unmarketable. 14

Halsted¹² has demonstrated recently the truth of the English statements to the effect that liming counteracts, to some extent, the tendency to "finger-and-toe" disease or "clubfoot" in the turnip, cabbage, and related plants. Possibly this is due to its producing soil alkalinity, a condition which might, perhaps, be unfavorable to that particular disease, even though the reverse is unquestionably true of the potato scab.

This view, taken from J. A. Voelcker's English experiments, shows the relative results of the use of lime, gas lime, and of no treatment for the "finger-and-toe" disease of turnips. At the top the sound turnips are at the right and in the other two cases at the left. Gas lime was used below and slaked lime above. The middle lots received no treatment.¹³ 15

METHODS OF APPLYING LIME TO CORRECT ACIDITY.

View.

16

In order to determine the relative effectiveness of lime in correcting soil acidity, when it was introduced into the soil, and when used as a top-dressing, the Rhode Island Experiment Station performed an experiment with timothy upon three plats of land.¹⁴ The manuring was the same in every instance. Upon one plat no lime was employed, upon another it was harrowed into the soil very thoroughly in the early autumn before the seed was sown, and upon the third it was weighed, left until the following spring, and then sown broadcast. Where the lime was worked into the soil, a good stand of timothy was secured, as seen at the right. Only a very small stand was obtained where the top-dressing of lime was used, and where it was omitted altogether timothy was entirely absent. In all except the first instance the product of the plats was chiefly weeds and grasses other than timothy. The lot of material in the middle was from the top-dressed area, and that at the left was from that which was unlimed.

OCCURRENCE OF ACID SOILS ELSEWHERE THAN IN RHODE ISLAND.

The occurrence of acid soils has been reported recently by the experiment stations of Alabama,¹⁵ New Hampshire,¹⁶ Oregon,¹⁷ Alaska,¹⁸ and Illinois.¹⁹ Maryland, Pennsylvania, and other States report benefit from liming under conditions which lead to the belief that the soils experimented upon were acid. The earlier experiment of Wagner and Dorsch,²⁰ and the more recent experiments at the Rhode Island Agricultural Experiment Station, noted above, have demonstrated the greater effectiveness of sulphate of ammonia after liming and shown that the beneficial effect of the lime in connection with this substance was due to its action in correcting soil acidity.

In this connection it is of interest to note that J. A. Voelcker, chemist to the Royal Agricultural Society of England, called attention in 1897 to the greater falling off of the yield of barley than of wheat in the Woburn experiments, where ammonium salts were used without mineral manures.²¹ This he attributed at first to ability on the part of wheat to send its roots lower than barley and thus get sufficient lime to serve as plant food; and he speaks of "sour" spots not furnishing an explanation of the failure of the barley, because it was a fault of the whole plat.

In 1901, however, he²² found, on testing the soil, that it had a distinctly acid reaction to litmus paper.

In discussing later results in 1902, he²³ says: "It would

appear that the acidity of the soil of plat 2a had acted injuriously upon the barley plants and stopped root development." A year later Voelcker adds:²⁴ "That the acidity of the soil, brought about by the continual use of ammonium salts, or else the condition of the soil consequent on its formation, is the cause of the failure of the land to produce barley and wheat." Voelcker found finally, in full agreement with the Rhode Island Station, that oats could thrive upon quite acid soil and that wheat could succeed better than barley.

Upon leaching the acid soil with water, and also upon very complete exposure of it to the air upon a stone floor for five months, with frequent turning, it was rendered capable of again supporting plants. The water used in leaching the soil was found after a time to have nearly lost its acidity. Upon soil where the conditions were probably nearly, if not quite, normal the addition of fresh leachings from the acid soil caused plants to turn yellow, and visibly affected not only barley but also oat plants.

The fact that the soil could support good growth after leaching with water effectually disposed of the original view held by Voelcker that the trouble was due to a lack of lime as plant food, for leaching would lessen rather than increase the lime.

A few illustrations taken from Voelcker's experiments are of interest.

This view shows the two plats which had been manured for a series of years with sulphate of ammonia and chlorid of ammonia. The right-hand plat, where few, if any, barley plants are to be seen, had not been limed. The plat at the left had received a dressing of lime at the rate of 2 tons per acre about three years before. Liming completely overcame the ill effect of the ammonium salts.

17

Where barley was grown with mineral manures and ammonium salts, injury to the crop was delayed somewhat, and though it was severe by 1898 it was less serious than where the ammonium salts were used alone. In the foreground it will be seen that much more barley is present than in the former view. Here the addition of lime to the soil the year before, at the rate of 2 tons per acre, entirely corrected the condition, as seen in the rear.

18

A. D. Hall, director of the Rothamsted Station, England, in discussing the permanent grass experiments at that station,²⁵ says that—

The long-continued use of manures like the ammonium salts, which are effectively acids, must have altered the reaction of the soil and made it sour

View.

on some of the plats. This is very palpable on a plat which has received a very heavy dressing of ammonium salts alone, and on which * * * there is now a large amount of sorrel, except upon a small portion where chalk had been applied.

He further adds:

A dressing of lime is, without doubt, necessary on grass land on moist soils in order to neutralize the acidity produced by decaying vegetation and to enable the manures to exert their full effect.

Hall²⁶ apparently fails to recognize that acid conditions are by no means confined to soils that are exceptionally moist, but are also likely to occur in light uplands. In fact, some of the acid soils experimented upon in Rhode Island were sandy and gravelly hillsides, where water could not stand, and where, nevertheless, a considerable amount of the humus was acid.

GENERAL OCCURRENCE OF ACID SOILS IN RHODE ISLAND.

After it had been demonstrated at the Rhode Island Station that the soil of the station farm was acid, the next step taken was to ascertain if the condition was quite general in the State. For this purpose plats of land were laid out in pairs in each county, the soil was tested for acidity, and experiments with barley, beets, clover, grass, and other crops were begun. In most of the cases the acidity of the soil, as shown by blue litmus paper and ammonia water, was quite marked. The plats were all manured alike with a complete artificial manure, lime being carefully worked into the soil of one of each pair of plats.

There will now be shown a succession of views illustrating the benefit from liming which was observed.

- 19 In the experiment at Foster Center²⁷ in 1896, with table beets, upon a soil which quickly and decidedly reddened blue litmus paper, the yields of beets upon the limed and unlimed plats were 143.4 and 36.6 pounds, respectively. The crop from the limed plat is shown at the right.
- 20 In a test with the same kind of beets at Slocum's²⁸ the unlimed plat yielded but 1 pound and the limed one 101.8 pounds. The barley crop (cut in the "milk") in this latter case was increased from 3.7 to 39.1 pounds by liming.
- 21 The experiment at Foster Center²⁹ was continued in 1897 with clover. The first crop upon the unlimed plat amounted to 140.2 pounds and upon the limed one to 195.6 pounds.
- 22 Upon acid soil at Hamilton, R. I.,³⁰ the first crop upon the grass section of the limed plat amounted to 205.1 pounds and consisted chiefly of timothy, mixed with a little redtop. Upon

the grass section of the unlimed plat, represented at the right, the total weight of grass was but 151.6 pounds. The grass was a mixture of about equal parts of timothy and redtop.

The clover section of the limed plat at Hamilton³¹ yielded 204.6 pounds, consisting of about equal parts of clover and redtop, mixed with a few other grasses. The corresponding unlimed section, represented at the right, yielded but 66.9 pounds, only 3.8 pounds of which was clover, the balance being chiefly redtop. The clover is the little lot, at the extreme right, beside the redtop, from which it was separated.

The second crop from the clover section of the limed plat at Hamilton³² weighed 74.4 pounds, and consisted of about equal parts of clover and grass. In striking contrast to this yield, but 0.1 pound of clover was obtained upon the unlimed plat. It was necessary to cut this with a pocketknife and place it in the straw hat, at the right, in order to render it visible in the photograph.

In a corresponding experiment upon the hill land at Kingston³³ the crops from the clover section of the two plats were harvested, and the clover and weeds were separated carefully. The two lots, at the left, represent the clover and weeds upon the limed section. The clover is at the extreme left, with the small lot of weeds at its right. The two piles at the right show the clover and weeds upon the unlimed section, the one at the extreme right being the weeds. It will be seen that where lime was used weeds were nearly lacking, but upon the unlimed section the weeds weighed nearly as much as the clover.

In an experiment at Moosup Valley, Rhode Island,³⁴ with mangel-wurzels (fodder beets), the unlimed area yielded at the rate of only a little over 3 tons per acre; but upon the limed area the yield was at the rate of over 20½ tons per acre. The view shows the exact relation of the crops, that from the unlimed area being represented at the right.

If time and space permitted, many more striking illustrations of a similar nature could be furnished, but it is sufficient to say that the many experiments demonstrated most completely that acid soils were quite general in Rhode Island, even on gravelly and sandy hillsides, and that great benefit from liming could be expected.

EFFECT OF ACIDITY ON PHOSPHATES IN THE SOIL.

Other experiments at the Rhode Island Station have given indications that quantities of phosphorus, double the amount said to be sufficient in certain soils for the support of crops for

View.

a series of years, may be present in an acid soil, and yet it may appear to be deficient in that element, as shown by actual plant tests.³⁵ Liming has been shown to apparently change a considerable amount of this phosphorus into such combinations that plants can utilize it, which is a distinct advantage, economically considered. Experiments at the same station, covering a period of ten years, have also shown that ignited iron and aluminum phosphate, or roasted redondite, one of the phosphatic constituents of certain commercial fertilizers, is of little or no value upon acid soil, but that its manurial efficiency is greatly increased by liming.³⁶

EFFECT OF ACIDITY ON DIFFERENT PLANTS.

The lime experiments of the most popular interest in connection with acid soil are probably those to ascertain the effect of soil acidity upon the growth of various plants. This line of work was begun at the Rhode Island Station in 1893, and about two hundred different kinds of plants have already been tested.³⁷ The trials were made upon four plats of land which were manured alike as concerns potassium, phosphorus, and magnesium. Each of the four plats received the same amount of nitrogen. Upon two of them it was applied in nitrate of soda, and upon the other two in sulphate of ammonia. One of each of these pairs of plats was limed at an equal rate, so as to reduce or overcome the acidity of the soil. The lines of plants were then run across each of the four plats. Before proceeding to show some of the results secured in this experiment, attention should be called to the fact that the plant assimilates the nitric acid of the nitrate of soda, and there is a tendency for soda to accumulate in the soil. On the other hand, where sulphate of ammonia is applied, the ammonia is changed to nitric acid within the soil and is taken up by the plants or leaches away in combination with bases, such as potash, lime, magnesia, or soda, thus leaving sulphuric acid behind, which in turn removes still more bases. Thus the tendency in using nitrate of soda is to reduce the soil acidity; and the tendency in using sulphate of ammonia, on the contrary, is to produce or increase acidity. For these reasons the chemical reaction of the plats, so far as concerns acidity and alkalinity, even if not limed, becomes quite unlike with the lapse of time. Even upon limed plats there is a tendency to acidity in the case of the plat receiving sulphate of ammonia, and to alkalinity in the one which receives nitrate of soda. For this reason, those plants which thrive much better

upon the unlimed plat which receives nitrate of soda than upon the corresponding one manured with sulphate of ammonia are the ones which, as a rule, are the most sensitive to soil acidity and consequently most helped by liming upon acid soils.

A general view of the plats will aid in making the subsequent views better understood. The path shown in the center passes between the two plats which receive sulphate of ammonia. The limed plat is on the left. It will be seen in the background that some kinds of plants were making a good growth, even upon the unlimed plat. The other two plats in the experiment, which are at the immediate left of these, are only partially seen. These receive nitrogen in nitrate of soda, the limed plat being at the left, as in this instance. 27

The view now upon the screen shows that amber cane (sorghum) and Kafir corn refused to grow upon the unlimed plat, where sulphate of ammonia had been used, even though the seed of each germinated satisfactorily. 28

This view shows the result with the same manures, but with the addition of lime. These plants evidently can not endure great acidity. 29

The two lots of tobacco at the left were from the plats manured with nitrate of soda, the two at the right from the plats which received sulphate of ammonia. The larger lot at the left in each pair was from the limed plat. 30

The results with rye, oats, wheat, barley, and sorghum are now shown. The products of the plats which received nitrate of soda are in each case on the left, and the left hand lot in each pair was from the limed plat. It will be recollected that lime was decidedly helpful in all of the cases where sulphate of ammonia was used. The result is, however, less marked with nitrate of soda. It will be observed that rye is least injured by acidity. This, in turn, is followed by oats, wheat, and barley, in regular order. The sorghum (early amber cane) was entirely killed upon the unlimed plat, which received sulphate of ammonia, which explains the presence of but three lots. It will be recollected that this is the same order in which Voelcker, of England, afterwards noted injury to oats, wheat, and barley upon the soil at Woburn, England, where ammonium salts had been used with ill effect. 31

In this view of German millet the crops produced by the aid of nitrate of soda are at the left. The crop at the extreme left, which was from the limed plat, was not as good as from the unlimed one. In the case where sulphate of ammonia was used 32

Vine.

liming proved helpful. It appears, therefore, that millet is unable to endure great acidity, though slight or moderate acidity seems more favorable to its growth than alkalinity.

- 33 The cantaloupe fails to thrive upon acid soil. In each instance the larger pile is from the limed plat. The crop from sulphate of ammonia is in each case poorer than from nitrate of soda.

- 34 The watermelon is the opposite of the cantaloupe, and its natural home seems to be upon acid soil. The small lots are, in both instances, from the limed plats.

The products with nitrate of soda, at the left, were in no case equal to that upon the very acid, unlimed plat which received sulphate of ammonia. It is of interest to see that the watermelon thrives best under soil conditions where Kafir corn, sorghum, barley, and the cantaloupe fail.

- 35 The cabbage is injured by soil acidity, for in both instances the limed lots are the better. Nitrate of soda, represented at the left, was superior to sulphate of ammonia.

- 36 Alfalfa is not suited by an acid soil, for on the unlimed plat manured with sulphate of ammonia every plant died. And even when nitrate of soda was used wonderful improvement was wrought by liming. The crop from the limed plat which received sulphate of ammonia is shown at the extreme left. The crop from the limed plat which received nitrate of soda is at the extreme right.

- 37 The relative amount of timothy and redtop in grass mixtures is materially influenced by the chemical reaction of the soil. Redtop can thrive upon very acid soil, but timothy can not; hence "the survival of the fittest" results under the conditions which happen to exist. Here is seen at the right the larger proportion of redtop upon the acid, unlimed plat which receives sulphate of ammonia.

- 38 It will be observed that upon the limed plat which receives sulphate of ammonia the major portion of the grass is timothy, the redtop being shown, as before, at the right. These Rhode Island experiments have shown why that State is famous for its Rhode Island bent. It is because the bent, like redtop, thrives upon acid soil. Kentucky bluegrass, timothy, and certain other grasses are likely to wholly disappear if the soil acidity becomes great.

- 39 Crimson clover can thrive upon soil that is slightly acid, but it is helped decidedly by liming on very acid soil. The two

large piles are from the limed plats. Upon the unlimed plat manured with sulphate of ammonia it practically failed.

In this view the plants from the two plats which received sulphate of ammonia are at the left and those manured with nitrate of soda are at the right. The plants in the second lot from the left and those at the extreme right are in this case from the limed plats. The carnation pink can exist upon very acid soil, but it is, nevertheless, greatly helped by liming. 40

The broom corn from the plats receiving sulphate of ammonia is at the left and from those receiving nitrate of soda at the right. The second lot from the left and the one at the extreme right were from the two limed plats. 41

The chicory roots are arranged in the same order as the broom corn and carnation pink. In this instance little or no difference in the yields resulted, and it is evident that chicory can be grown successfully even upon quite acid soil. 42

The order of arrangement of the flax shows the results with sulphate of ammonia at the left and with nitrate of soda at the right. The products in the second bundle from the left and at the extreme right show little, if any, benefit from liming. Flax, therefore, like chicory, is well adapted to acid soil. 43

The onion which is now shown stands in striking contrast to chicory and flax, for only one or two very small onions were obtained from the unlimed plat, manured with sulphate of ammonia. 44

In the case of the two lots at the right, which were grown with the aid of nitrate of soda, liming raised the yield from 24 pounds to 44.3 pounds.

These results appear to give the first satisfactory explanation why farmers in certain sections of the country have been unable to grow onions successfully with commercial fertilizers. In certain instances the recent use of lime has overcome the difficulty.

For the same reason the poppy, which thrives upon an alkaline soil, has never been able to gain a foothold as a weed in regions where acid soils abound, a fact which the Rhode Island experiments have demonstrated and which may be useful to the United States Department of Agriculture in its attempts to grow the poppy for the production of opium. This should be a useful hint to those who grow the poppy either for the flowers or seed.

The serradella, unlike sainfoin, the clovers, the lentil, vetch, peas, and certain other legumes, thrives readily upon soil that 45

View.

is sufficiently acid to almost utterly prevent the growth of onions, lettuce, spinach, beets, cantaloupes, asparagus, and many other plants. In fact, the two lots at the left, grown with the aid of sulphate of ammonia, were apparently as good as those at the right, which were manured with nitrate of soda.

It has been found that liming heavily immediately before growing the crop, though very helpful to red clover, results injuriously to the serradella.

The soy or soja bean and the southern cowpea are two other legumes which are little in need of liming just before they are to be grown even upon quite acid soil, though in subsequent years the liming may show beneficial effects upon their growth. This benefit from liming in subsequent years is possibly true of the soy bean to a greater extent than of the cowpea.

- 46 Every lover of pumpkin pies will be glad to know that the liming of acid soil promotes the growth of the pumpkin. The marked advantage of nitrate of soda over sulphate of ammonia is shown by the better pumpkins in the two piles at the right, as compared with the two corresponding lots at the left, grown with the aid of sulphate of ammonia. The second pile from the left and the one at the extreme right illustrate, when compared with those at their immediate left, the advantage from liming the soil.

- 47 But three lots of asparagus plants are shown, for the reason that all of the plants upon the unlimed plat, which received sulphate of ammonia, died during the first and second years after they were set. The greater size of the tops shown at the right, as compared with the lot in the middle, illustrates the advantage from liming, even when nitrate of soda was employed. The results upon the limed plat which received nitrate of soda were decidedly better than upon the limed plat where sulphate of ammonia was used. The yields of marketable asparagus stood in the relation of 9.62 to 5.87 pounds upon the respective plats.

- 48 The cranberry plants grew best of all upon the unlimed plat where sulphate of ammonia had been applied. This is represented by the lot at the extreme left. The lot at the immediate right of it shows the great injury which may result from liming. Again, where nitrate of soda was employed the vines from the limed plat, which are shown at the extreme right, are much inferior to those at the immediate left, where lime was omitted.

- 49 These marked differences in the relation of plants to soil conditions are not confined to herbaceous plants, for even the

quince, as seen, is much helped by liming. The two results with sulphate of ammonia are at the left and with nitrate of soda at the right. The second bush from the left and the one on the extreme right are the ones grown upon the limed plats.

The Norway spruce, unlike the quince, is injured by liming. The right-hand tree of the left pair, manured with sulphate of ammonia, is inferior to the one on the extreme left, where no lime was used. Again, looking at the right-hand pair, which grew upon the plats where nitrate of soda was used, the right-hand or limed one is inferior to the other. 50

The pair of apple trees at the left grew upon the plats which received sulphate of ammonia and the pair at the right where nitrate of soda was used. The better growth of the tree at the right of each pair shows that lime was advantageous. Nevertheless, apple trees can grow fairly well upon soil which is quite acid. What the effect of liming would be upon the yield of fruit and the quality of the product could not be ascertained, owing to the necessary removal of the trees after a few years' growth. 51

The influence of liming acid soil upon the quantity of hay produced is well illustrated in a series of experiments with different phosphates at the Rhode Island Station. There are ten plats upon unlimed land, one of which receives no phosphatic manure, nine different kinds of phosphates being employed upon the remainder of the plats.

The ten piles of hay show the crop from these ten unlimed plats. The treatment of the plats with phosphatic manures, beginning at the left, is as follows: First, dissolved bone-black, dissolved bone, acid phosphate, finely ground bone, basic slag meal, floats, raw iron and aluminum phosphate, ignited iron and aluminum phosphate, no phosphate, and double super-phosphate. 52

The crops upon the ten limed plats are, as will be seen, much greater than upon the acid soil, where lime was omitted. The same order of phosphatic manuring, from left to right, was followed as in the preceding instance. A most interesting feature of this experiment is the fact which has been mentioned already, viz, that ignited iron and aluminum phosphate, also known as roasted redondite, which contains about 35 per cent of reverted or available phosphoric acid, is of very inferior value, even immediately, when used upon acid unlimed soil, and so far as its after effect is concerned it amounts to practi- 53

View.

cally nothing upon most agricultural plants. When the soil is limed, however, both the immediate and after effects are much increased. These facts emphasize the necessity of testing soils and of liming, if necessary, if it is hoped to secure good returns from such ready-mixed commercial fertilizers as contain much ignited iron and aluminum phosphate. Nevertheless, good crops of such plants as are not greatly injured by acidity can still be produced for a series of years under the same conditions without liming, provided the phosphorus is supplied in basic slag meal, bone (either steamed or acidulated), acid phosphate, dissolved bone-black, or double superphosphate.

From what has been shown in this lecture it seems probable that there is a certain chemical reaction of the soil that represents the best condition for each kind of plant. Many of those best suited by a certain degree of acidity seem nevertheless to thrive where a considerable degree of alkalinity exists. On the other hand, certain plants that appear to thrive best on an alkaline soil are able to endure considerable acidity. There are also groups of plants which are very sensitive to any wide departure in either direction from the optimum. The Rhode Island experiments with plants are being conducted upon plats representing four different degrees of acidity or alkalinity, and hence throw considerable light upon the range of various plants, at least so far as concerns their limits, for acidity.

It is not expected that every person who has an acid soil will derive the same benefit from liming that has been observed in Rhode Island, unless the soil is equally acid and the physical and other conditions are similar, yet the Rhode Island experiments ought to serve a very useful purpose as a guide to the manurial treatment of acid soil in adapting it to the particular crops to be grown.

The facts which have been presented teach that there is still much to learn concerning the individual requirements of field crops which has heretofore been neglected, and which must be taken into account in a rational system of agriculture.

SUGGESTIONS REGARDING THE USE OF LIME ON ACID SOILS.

For the benefit of those who may desire to employ lime, a few practical suggestions about liming may not be out of place at this point.

First. Sandy soils should not be limed heavily. For such soils carbonate of lime and wood ashes are to be preferred. If slaked lime is to be used upon such soils, that which has been

long exposed to the air is best. Half a ton to a ton of slaked lime per acre or twice that quantity of either ground limestone or wood ashes may be used in a single application.

Second. For very heavy clay soils, or such as are rich in sour humus, twice as large amounts of lime may be used as for sandy soils. For use upon such soils pulverized burned lime or water-slaked lime may sometimes be preferable to finely ground limestone or wood ashes.

Third. To make liming immediately effective, the material should be spread upon the furrows and be harrowed into the soil most thoroughly. When applied in grain drills its benefits are often not strikingly noticeable the first year, owing to the fact that it does not become intimately mixed with the soil until after the first season.

Fourth. After being sown, the lime should not lie upon the surface over night or during a storm, but it should be introduced into the soil at once. If potatoes are grown in rotations, the liming should follow the removal of the potato crop. One exception to this might be made if potatoes must be grown at the outset when one is taking up acid-exhausted soil. In such a case it is often better to lime before planting the first crop, though in later years liming should be deferred until after the potatoes are harvested. In no case should treatment of the "seed" tubers with corrosive sublimate solution (1 to 1,000) or formalin be omitted, or serious injury from potato scab will be likely to result.

Fifth. In liming in the course of a rotation, applications at intervals of from five to six years are usually sufficient. The lime should, if possible, be applied just before a crop which is especially likely to be helped by it, and the more indifferent crops may be introduced later.

Sixth. The lime may be slaked in small piles in the field or in larger piles at one side, or it may be air-slaked in a water-tight building, so that there may be no danger of fire. In the case of small piles, some moist soil thrown over the lime facilitates slaking. Sprinkling the burned lime with the proper amount of water will make it slake quickly to a powder. Full directions for slaking and using lime are to be found in Farmers' Bulletin No. 77, published by the United States Department of Agriculture.

Seventh. Magnesian lime may sometimes be used to advantage in place of pure lime, but it should not be used repeatedly on the same land.

Eighth. Other substances than lime may be used to correct

View.

the condition of acid soils, yet none of them are likely to be so quick and lasting in their effects, so cheap to apply, and so little liable to produce other undesired results as lime.

Ninth. It should be remembered that land plaster, also known as gypsum and sulphate of lime, is not capable of taking the place of wood ashes, slaked lime, ground burned lime, or pulverized limestone in neutralizing soil acidity.

APPENDIX.

LANTERN SLIDES.

No. of
view.

1. Indian corn, Kingston, 1893.
Shows in foreground, center three rows, effect of 240 pounds sulphate of ammonia per acre.
2. Indian corn, Kingston, 1893.
Effect of 240 pounds sulphate of ammonia per acre used with lime.
3. Indian corn, Kingston, 1893.
Effect of 360 pounds sulphate of ammonia per acre used with lime.
4. Indian corn, Hope Valley.
Explanation on the photograph.
5. Lettuce. Nos. 57, 58, 59, 60. (Pot numbers used in the original station publications.)
Lots 57 and 58 without sodium carbonate. Lot 59 with a half ration. Lot 60 with a full ration.
6. Barley.
Showing effect of lime, caustic magnesia, magnesium sulphate, and sodium carbonate, with sulphate of ammonia.
7. Barley.
Showing effect of caustic magnesia, sodium carbonate, wood ashes, potassium chlorid, and potassium carbonate, with sulphate of ammonia.
8. Barley.
Showing effect of lime, caustic magnesia, and magnesium sulphate, with sulphate of ammonia.
9. Barley.
Showing effect of nitrogenous manures upon acid soils.
10. Barley.
Showing effect of nitrogenous manures upon limed soil.
11. Potatoes.
Scab experiments, air-slaked lime and unlimed.
12. Potatoes.
Scab experiments, calcium sulphate and calcium chlorid.
13. Potatoes.
Scab experiments, calcium carbonate and calcium oxalate.
14. Potatoes.
Scab experiments, calcium acetate and wood ashes.
15. Turnips.
English experiment, "finger-and-toe" disease.
16. Timothy experiment.
Lime worked into soil and as top-dressing, left-hand lots unlimed.
17. Barley, Woburn, England.
Ammonium salts with and without lime.

No. of
view.

18. Barley, Woburn, England.
Ammonium salts and minerals.
19. Beets, Foster Center, R. I.
Unlimed. Limed.
20. Beets, Slocums, R. I.
Unlimed. Limed.
21. Clover, Foster Center, R. I.
Limed. Unlimed.
22. Grass, Hamilton, R. I.
Limed. Unlimed.
23. Clover and grass, Hamilton, R. I.
Limed. Unlimed.
24. Clover, Hamilton, R. I.
Second crop. Limed. Unlimed.
25. Clover and weeds, Kingston, R. I.
Limed: Clover, weeds. Unlimed: Clover, weeds.
26. Mangel-wurzel, Moosup Valley, R. I.
Limed. Unlimed.
27. General view.
"Sulphate of ammonia" plats, Kingston, R. I.
28. Kafir corn and sorghum.
Showing failure upon very acid soil.
29. Kafir corn and sorghum.
Showing growth after liming.
30. Tobacco.
Limed, unlimed: Nitrate of soda. Limed, unlimed: Sulphate of ammonia.
31. Oats, rye, sorghum, wheat, and barley.
Limed and unlimed.
32. Millet.
Limed, unlimed: Nitrate of soda. Limed, unlimed: Sulphate of ammonia.
33. Cantaloupe.
Limed, unlimed: Nitrate of soda. Limed, unlimed: Sulphate of ammonia.
34. Watermelon.
Limed, unlimed: Nitrate of soda. Limed, unlimed: Sulphate of ammonia.
35. Cabbage.
Limed, unlimed: Nitrate of soda. Limed, unlimed: Sulphate of ammonia.
36. Alfalfa.
Limed, unlimed: Nitrate of soda. Limed, unlimed: Sulphate of ammonia.
37. Timothy, redtop.
Unlimed plat, sulphate of ammonia.
38. Timothy, redtop.
Limed plat, sulphate of ammonia.
39. Crimson clover.
Limed, unlimed: Nitrate of soda. Limed, unlimed: Sulphate of ammonia.
40. Carnation pink.
Unlimed, limed. Sulphate of ammonia. Unlimed, limed: Nitrate of soda.
41. Broom corn.
Unlimed, limed: Sulphate of ammonia. Unlimed, limed: Nitrate of soda.
42. Chicory.
Unlimed, limed: Sulphate of ammonia. Unlimed, limed: Nitrate of soda.
43. Flax.
Unlimed, limed. Sulphate of ammonia. Unlimed, limed: Nitrate of soda.

No of
view.

- | | |
|--------------------------------------|----------------------------------|
| 44. Onions. | |
| Unlimed, limed: Sulphate of ammonia. | Unlimed, limed: Nitrate of soda. |
| 45. Serradella. | |
| Unlimed, limed: Sulphate of ammonia. | Unlimed, limed: Nitrate of soda. |
| 46. Pumpkin. | |
| Unlimed, limed: Sulphate of ammonia. | Unlimed, limed: Nitrate of soda. |
| 47. Asparagus tops. | |
| Unlimed, limed: Sulphate of ammonia. | Unlimed, limed: Nitrate of soda. |
| 48. Cranberry vines. | |
| Unlimed, limed: Sulphate of ammonia. | Unlimed, limed: Nitrate of soda. |
| 49. Quince. | |
| Unlimed, limed: Sulphate of ammonia. | Unlimed, limed: Nitrate of soda. |
| 50. Norway spruce. | |
| Unlimed, limed: Sulphate of ammonia. | Unlimed, limed: Nitrate of soda. |
| 51. Apple trees. | |
| Unlimed, limed: Sulphate of ammonia. | Unlimed, limed: Nitrate of soda. |
| 52. Grass. | |
| Unlimed phosphate plats. | |
| 53. Grass. | |
| Limed phosphate plats. | |

REFERENCES.

1. Agriculture, 2 (1901), p. 255. The Home Correspondence School, The King-Richardson Co., Springfield, Mass.
2. Rhode Island Sta. Rpt. 1901-2, pp. 295-304.
3. Rhode Island Sta. Rpt. 1890, pp. 49-56.
4. Rhode Island Sta. Rpt. 1893, p. 203.
5. Rhode Island Sta. Rpt. 1895, p. 267.
6. *Ibid.*, p. 269.
7. *Ibid.*, p. 31.
8. Rhode Island Sta. Rpt. 1899-1900, p. 302.
9. *Ibid.*, p. 311.
10. Rhode Island Sta. Rpt. 1897, pp. 241-249.
11. Rhode Island Sta. Bul. 40, also several previous bulletins, referred to therein.
12. New Jersey Stas. Rpts. 1894, p. 285; 1895, p. 265; 1896, p. 304.
13. Jour. Roy. Agr. Soc. England, 64 (1903), p. 347.
14. Rhode Island Sta. Rpt. 1899, pp. 171-173.
15. Alabama College Sta. Bul. 92, pp. 107-112.
16. New Hampshire Sta. Rpt. (Bul. 59), pp. 181, 182.
17. Oregon Sta. Rpt. 1898, p. 41.
18. U. S. Dept. Agr., Office of Experiment Stations Bul. 82.
19. Illinois Sta. Circ. 64.
20. Die Stickstoffdüngung. Berlin: Paul Parey, 1892, pp. 216-219.
21. Jour. Roy. Agr. Soc. England, 3. ser., 8 (1897), pp. 287, 288.
22. Jour. Roy. Agr. Soc. England, 62 (1901), p. 286.
23. Jour. Roy. Agr. Soc. England, 63 (1902), p. 314.
24. Jour. Roy. Agr. Soc. England, 64 (1903), p. 361.
25. *Ibid.*, p. 93.
26. The Soil. New York: E. P. Dutton & Co., 1903, pp. 157, 158, 221.
27. Rhode Island Sta. Rpt. 1896, after p. 288, fig. 10.
28. *Ibid.*, fig. 11.
29. Rhode Island Sta. Rpt. 1897, after p. 198, fig. 5.
30. *Ibid.*, fig. 1.
31. *Ibid.*, fig. 2.
32. *Ibid.*, fig. 3.
33. *Ibid.*, fig. 17.
34. *Ibid.*, fig. 19.
35. Rhode Island Sta. Rpt. 1898, pp. 122-132.
36. Massachusetts State Bd. Agr. Rpt. 1903, p. 153.
37. Rhode Island Sta. Rpts. 1893, pp. 224-252; 1894, pp. 152-167; 1895, pp. 205-214; 1896, pp. 224-272; 1897, pp. 202-225; 1898, pp. 144-170; Buls. 69, 96.

UNIVERSITY OF FLORIDA



3 1262 08929 2071